MERG Report 2000-5

Faro Tailings Area Down-Hole Geophysics Program to Study Contaminant Plumes

By EBA Engineering Consultants Inc.

MERG is a cooperative working group made up of the Federal and Yukon Governments, Yukon First Nations, mining companies, and non-government organizations for the promotion of research into mining and environmental issues in Yukon.

EBA Engineering Consultants Ltd.

DOWNHOLE GEOPHYSICS PROGRAM, FARO TAILINGS AREA
ROSE CREEK, FARO, YUKON

Submitted To:

POLLUTION ABATEMENT, YUKON DIVISION
ENVIRONMENTAL PROTECTION, WHITEHORSE, YUKON

Prepared by:

EBA ENGINEERING CONSULTANTS LTD.
WHITEHORSE, YUKON

Prepared for:

YUKON MINE ENVIRONMENT RESEARCH GROUP

Project No. 0201-00-14352

APRIL, 2000

Unit 6 – 151 Industrial Road, Whitehorse, Yukon, Canada, Y1A 2V3 – Tel (867) 668-3068 – Fax (867) 668-4349
Internet: whitehorse@eba.ca - Web Site: http://www.eba.ca

EXECUTIVE SUMMARY

A Geophysical Program was conducted at 5 groundwater monitoring wells on March 14, 2000 at the Faro Tailings Area, Rose Creek, Faro, Yukon under the auspices of the Yukon Government's Mine Research fund, DIAND Mineral Resources and Environment Canada by EBA Engineering Consultants Ltd.

The EM39 geophysical instrument is able to measure the electrical conductivity of the ground within about 1 meter of the probe. The probe is a cylinder 3.6 cm in diameter and 1.6 m long. The probe is slowly lowered down a water well and as it is lowered it measures the conductivity of the soils surrounding the well. As the probe is lowered any changes in the electrical conductivity of the ground indicates either: 1) changes in the levels of contaminants (metals like zinc in this case) in the ground, or; 2) changes in the type of soil - for example if there is sand and then a layer of clay or silt. In order to distinguish whether the change is due to 1) or 2) a gamma probe was also used. The gamma probe is also slowly lowered down the well and it only measures changes in the type of soil. By comparing the readings of the two probes you can determine what vertical zones in the soil were being affected by changes in the levels of contaminants in the soil and the soil's groundwater.

Groundwater monitoring wells normally are simply a long plastic pipe well with a slotted section typically 1 to 2 metres long at the end. Groundwater seeps into the well at the slotted section (called a well screen) and a sample can be collected and analyzed for contaminants. At Faro, it is believed that the most heavily contaminated groundwaters, which are found close to the tailings, may exist mostly in parts of the groundwater only 0.5 to 2 metres thick. So if the well screen is not installed at the proper depth then this contaminated zone will be undetected. A primary objective of this investigation was to determine whether geophysical instruments might allow us to find the position of these contaminated zones so that well screens can be installed at the proper depths to measure the extent of contamination and whether it is increasing or decreasing over the years.

This investigation in the Faro tailings area was successful. Four zones of elevated conductivity readings were detected in three of the wells. Two zones each 1 m thick were identified immediately at the base and/or below the tailings in monitoring well 96-05C (see Figure 1). Two thin zones 0.25m thick were identified within 5 m of grade and close to the water table elevation in monitoring wells X16B and X17B. All other conductivity data showed no evidence of contamination in the groundwater below and downstream of the tailings.

In addition to those four zones, the conductivity profile within the tailings at monitoring well 96-05C showed seven distinct layers. These layers are thought to be due to a combination of changes in the sandiness or siltiness of the tailings over time and/or evidence of the metals being leached out of the tailings because of increasingly acidic conditions in the tailings.

The gamma probe data shows a similar pattern of soil types with depth within the natural overburden at all monitoring wells. Within the tailings at monitoring well 96-05C there is evidence of elevated lead levels as well as some evidence of the lead being leached out in the top 1.5 m of the tailings profile. There is a general correlation in the gamma probe data with the more water permeable zones noted when the wells were originally drilled.

Although the geophysical conductivity and natural gamma logs successfully characterize the 5 monitoring wells examined it is concluded that the monitoring wells are too far apart to relate the individual results in a meaningful fashion. In addition, only one monitoring well (X17B) extends down all the way to the bedrock, therefore it is unknown as to what conditions may be present below the other 4 monitoring wells.

It is recommended that new monitoring wells be placed at strategic locations dictated by an understanding of the groundwater flowpaths of the site. It is also recommended that in order to optimize the placement of screened intervals the wells should be installed in a fashion that would allow geophysical conductivity logging prior to final placement of the well screens.

TABLE OF CONTENTS

FIGURES

APPENDICES

1.0 INTRODUCTION

EBA Engineering Consultants Ltd. (EBA) was retained by the Pollution Abatement Section, Yukon Division of Environment Canada to provide geophysical well logging services at up to 8 wells at the Rose Creek Tailings Ponds at Faro, Yukon. This data was collected by Mr. Neil Parry of EBA on March 14, 2000. The program was a follow up to recommendations put forward in a Groundwater Hydrological Study carried out earlier by another consultant. Specifically, the hydrological report indicated that it was possible that contaminated water from the tailings could be present in thin layers between the current screening intervals of the existing monitoring wells. Identification of these layers, if present, was desirable if adequate monitoring and understanding of the site conditions was to be obtained. Funding for this project was provided by the Yukon government's Mine Environment Research fund, DIAND Mineral Resources and Environment Canada.

2.0 OBJECTIVES

The objective of the geophysical logging program was to collect vertical conductivity and lithological data at 8 monitoring well locations in the Rose Creek Tailings complex. The wells logged were 96-05C, 96-04D, 96-03B, X17B and X16B. Figure 1 shows the location of these wells. In order to successfully log these wells the geophysical tools had to able to fit down wells with an inside diameter of 5 cm. In addition they had to be capable of detecting layers as thin as 0.25 m thick. To meet these objectives two geophysical tools were used, a Geonics EM39 Conductivity Probe and a Geonics Gamma39 Probe.

Of specific interest were the data from well 96-05C. At this monitoring well there was a desire to log the conductivity profile to see if a thin layer of contaminated ground water was present immediately below the base of the tailings.

3.0 AUTHORIZATION

Authorization to proceed was received in two phases. Phase 1 consisted of providing a dummy probe to check the existing monitoring wells for obstructions. This was authorized by Vic Enns of The Pollution Abatement Section, Yukon Division, Environment Canada under PO KE625-9-5317 on January 10th, 2000. The holes were checked by mine personnel using a dummy probe during the week of January 17th, 2000. Based on the results of these checks, 5 holes were identified as suitable candidates for geophysical logging. Authorization for the second phase was by Contract KE625-9-5317 on February 14th, 2000.

4.0 SITE LOCATION

The Faro mine was developed from a lead-zinc massive sulphide deposit mined from 1969 to 1998. Approximately 40 million tonnes of acid generating tailings have been deposited in the Rose Creek Valley. The tailings complex consists of a series of three impoundments. The first tailings impoundment is referred to as the Original impoundment and was used until 1974. The second tailings impoundment is referred to as the Second impoundment and starts immediately below the Original impoundment dam and was used until 1986. The third tailings impoundment is referred to as the Intermediate impoundment and extends from the toe of the Second impoundment dam downslope to the Intermediate dam. This tailings impoundment is the largest and was used from 1986 to 1993. Below the Intermediate dam there is a polishing pond to treat the impoundment effluent prior to discharging it into Rose Creek. This pond is referred to as the Cross Valley Pond and is retained by the Cross Valley Dam. The monitoring wells logged are in three groups. The first group X16B and X17B is downstream of the Cross Valley Dam in natural overburden. The second group 96-03B and 96-04D is immediately below the Intermediate Dam and is also primarily in natural overburden with the exception of the top five metres that is granular fill originating from the construction of the Intermediate Dam. The final hole, 96-05C, is at the toe of the Second impoundment dam. There are several other wells in this area but only 96-05C was logged for the following reasons.

1. It is the only well screened below the tailings
2. It is the only well in this area with a large enough hole diameter to permit logging.

Figure 1 shows the layout of the wells. Table 1 provides approximate ground elevation and overburden thickness at each monitoring well.

Table 1
Surface Elevation and Overburden Thickness

	Surface Elevation	Well Depth	Overburden Thickness
X16B	1021.0 m	30.5 m	52.7 m (DH81-K1)
X17B	1022.0 m	22.9 m	22.9 m (DH81-K2)
96-03B	1031.4 m	19.8 m	>19.8 m (~40 m?)
96-04D	1032.3 m	30.6 m	>30.6 m (~40 m?)
96-05C	1051.4 m	29.9 m	>29.9 m (~50 m?)

Ground water levels vary with the water table being around 3.5 to 4 m below ground elevation at 96-05C, approximately 1 m below surface at the toe of the Intermediate dam, and 2 to 4 m below ground elevation downstream of the Cross Valley Dam. The high water table immediately below the Intermediate dam is associated with the water level of the Cross Valley Pond.

5.0 METHODOLOGY

A Geonics EM39 logging system was used at all monitoring wells. Two probes were used, an EM39 conductivity probe and a Gamma39 probe. The probes were logged using an electric winch system with a cable odometer to trigger the logging system at preset intervals.

5.1 Equipment Specifications

Detailed specifications for the EM39 conductivity probe and Gamma39 natural gamma probe are outlined in Table 2.

Table 2
Detailed Equipment Specifications

EM39	
Measured conductivity:	in millisiemens per metre (mS/m)
Primary Field Source:	Self-contained dipole transmitter
Sensor:	Self-contained dipole receiver
Intercoil Spacing:	0.5 m
Operating Frequency:	39.2 kHz
Conductivity Ranges	+- 100, 1000, 10000 mS/m
Max Depth:	500 m
Measurement Precision:	+-0.1% of the full scale
Measurement Accuracy:	+-5% at 30 mS/m
Noise Level:	<0.5 mS/m
Dimensions:	3.6 cm diameter, 163 cm length
Measurement Point:	84 cm from tip
Weight:	2.2 kg
Gamma39	
Measured quantity:	Naturally occurring gamma-radiation, in counts/second
Sensor:	Thallium activated sodium iodide crystal
Counts Range:	100, 300, 1000 counts/second
Max Depth:	500 m
Measurement Precision:	one count/second
Dimensions:	3.6 cm diameter, 100 cm length
Measurement Point:	5 cm from tip
Weight:	1.6 kg

A detailed discussion of the theory behind the measurements is discussed in Appendix A.

5.2 Survey Procedure

Survey procedure was the same for each well. Prior to logging each well the watera was removed and the dummy probe was lowered down to the bottom of the well to check for obstructions. Wells 96-03B and 96-04D had between 30 and 50 cm of ice plugging the hole near surface and this was thawed using a heating system and a portable generator.

The cable odometer was set to trigger at intervals of 0.025 m and the winch speed was monitored and maintained at a speed of approximately 0.05 m/s plus or minus 0.01m/s. The conductivity probe was logged first, followed by the gamma probe. Both probes were logged down the well and then up resulting in redundant check logs. The conductivity probe was zeroed at each monitoring well by nulling the reading while holding the probe vertically 2 m off the ground at least 5 m away from any metal. As the probe is insensitive to influences more than 1.5 m from the probe this procedure is effective in calibrating the system under all conditions present at the site. The gamma probe was factory calibrated prior to the fieldwork and was not checked in the field. All readings were referenced to the top of the PVC casing and the stickup to true ground elevation was measured to allow all readings to be corrected back to a true ground reference. The measurement point for each probe was used as the zero reference. In the case of the conductivity probe this point was 0.84 m from the probe tip, in the case of the Gamma probe this point was 0.05 m from the probe tip. All data was digitally logged to a PC laptop in the field.

5.3 Accuracy

All logs were cross-checked by comparing the up and down logs. The conductivity logs were repeatable indicating that the conductivity probe was operating within specifications. The natural gamma results rely on statistical probabilities, therefore results at a specific point in time at one location will vary with an average value and a standardized distribution, but comparisons between the up and down gamma logs show the same trends and scatter in the results, providing confidence in the results.

As the probes are logged at a constant speed a vertical positional error is generated as a function of the integration time of the sensor taking the reading. This error is quantifiable and is approximately 0.09 m given the average winch speed of 0.05 m/s used during this program. This error is zeroed out by averaging the logged depths for both the up and down logs.

Finally, there is some uncertainty in correlating some the original well logs with the geophysical logs, in order to determine absolute log elevations. These are discussed in the results section for each well.

5.4 Limitations

The limitations inherent in conductivity logging and natural gamma logging are detailed below in point form.

1. The ability of the conductivity probe to resolve thin layers is a function of the intercoil separation of 0.5m and the bulk averaging conductivity effect (apparent conductivity) seen in layered media when measuring this property using an alternating (AC) electrical field. Tests under controlled conditions and modeling of the conductivity probe's electrical characteristics have developed the following relationships between layer thickness, apparent conductivity values and true conductivity values. For layers thinner than 0.75 m the following equation describes the magnitude of the apparent conductivity measured and its relationship to the true conductivities of surrounding layers.

   Equation 1. .... $\sigma_a = (\sigma_2 - \sigma_1)t$

   where : -

   σ_a = measured apparent conductivity of layer 2
   σ_1 = measured apparent conductivity of layer 1
   σ_2 = measured apparent conductivity of layer 2
   t = thickness of layer 2

   If the layers are between 1.5 m and 5 m thick then the bulk averaging effect dictated by the interaction of layered media in an alternating (AC) electric field determines the value of the apparent conductivity measured. The apparent conductivity measured will be within 20% of the true value and this relationship is described by the following equation.

   Equation 2. .... $(\sigma_2 - \sigma_a)/(\sigma_2 - \sigma_1) < 0.2$

For layers between 0.75 m and 1.5 m thick the relationship between the apparent conductivity and the true conductivity is between the above two relationships. As the thickness of layers within this range can be clearly resolved by measuring the separation between the half amplitude maximum on the rising and falling edge of the measured conductivity response the true conductivity can be calculated using modeling techniques.

If the layer thickness is greater than 5 m thick then the apparent conductivity is approximately equal to the true conductivity.

The intercoil spacing of 0.5 m determines the minimum layer thickness that can be unambiguously resolved. This is due to the fact that if the layer is less than half of the intercoil spacing thick, i.e. 0.25 m, then the width of the conductivity response measured is independent of the layer thickness and therefore either the layer thickness or the true conductivity must be known to uniquely model the layer using equation 1.

2. The vertical positional accuracy is a function of the logging speed For this program the logging speed was one reading every 2.5 cm, therefore positional accuracy is theoretically 1.25 cm (2.5 cm / 2). In practice the vertical positional accuracy is more a function of errors in referencing the log to true ground elevation.

3. The conductivity probe is optimized to measure apparent conductivity's within a 1 m radius of the well being logged, therefore changes in conductivity further away will not be detected. This also means that the conductivity of the water in the well does not affect the value of the apparent conductivity measured.

4. The natural gamma log is sensitive to gamma ray particles resulting from three naturally occurring atomic decay sequences (see Appendix A). Generally speaking, the amount of gamma ray particles detected can be correlated with the presence or absence of fine grained clay particles and therefore permeability. However it is possible that the host soil may simply lack material that falls into one of the three atomic decay sequences that the detector is sensitive to, or there may be material that naturally absorbs gamma particles (lead would be an example of such a material). Conversely if a natural (or artificial) active source of gamma radiation is present in the soil (such as monazite) this can also skew the results.

5.5 Term Definitions

The following terms are used in the discussion of the results and have very specific meanings. They are therefore defined in the following section.

1. Apparent Conductivity:

The apparent conductivity of a material is the measured conductivity. Due to bulk averaging effects introduced by the interaction of the measurement technique and the presence of layered material the measured conductivity is different from the actual conductivity of the material. The thicker the layer, the closer the measured conductivity is to the actual conductivity.

2. True Conductivity:

The true conductivity of a material is the actual conductivity one would measure if one removed all sources of measurement error. It is a bulk property of the material in question and is a function of the chemical composition of its constituent particles.

3. Modeled Conductivity:

The modeled conductivity is a approximation of the true conductivity profile based on the characteristics of the measurement tool, the layer thickness model and the measured apparent conductivity profile. The objective is to create a layer thickness model that, when combined with a modeled conductivity profile, matches the measured apparent conductivity profile. If this is achieved, and the model values agree with external data such as borehole logs, then one can assume that the modeled conductivity is representative of the true conductivity values.

4. Inphase Readings:

The inphase measurement is in fact a unitless ratio expressed in parts per thousand (ppt) between the magnitude of the induced primary magnetic field and the magnitude of the measured secondary magnetic field that is inphase electrically with the primary. In practical terms it provides a means of detecting metallic objects in that when no metal is present the instrument is calibrated such that the inphase reading is the same as the conductivity reading, but when metal is present the inphase reading will show a positive and/or negative peak. The magnitude of the peak is a function of the mass, geometry and proximity of the metal object.

5. Resolution:

The resolution of an instrument is defined as the smallest interval that it can distinguish based on its design specifications. One needs to be careful in any discussion of an instrument's resolution as to exactly what quantity one is talking about. For instance, in the case of the EM39 the intercoil spacing of 0.5 m determines that the absolute limit in resolution as far as directly measuring a layer thickness is 0.25 m. However the resolution to which that layer can be located below grade (depth) is actually a function of the logging speed and at typical logging speeds is 0.1 m.

6.0 RESULTS

6.1 Overview

Geophysical logs were collected for 5 monitoring wells, X16B, X17B, 96-03B, 96-04D, and 96-05C. All data has been corrected to a true ground elevation (0 m) and the results have been plotted and presented with the borehole logs compiled when the monitoring wells were installed. The results are shown in Figures 2 to 6. From left to right the following logs are shown; natural gamma profiles, measured apparent conductivity and inphase profiles, model and calculated apparent conductivity profiles and borehole log.

Although the result for each monitoring well will be individually discussed in the following sections some general observations concerning the results as a whole are appropriate. These comments are listed below:

1. Conductivities measured are generally low in the native overburden material, ranging between 5 and 20 mS/m. These values are typical for silty sands, glacial tills and river sands and gravels and do not suggest significant electrolytic contaminants within this material.

2. The natural gamma logs do show some correlation with the borehole logs in that the less permeable zones correlate with the silt beds and the more permeable zones correlate with the clean sands and gravels.

3. There is considerable fluctuation in the natural gamma logs within the natural overburden material and the fluctuations usually correlate when comparing the up and down logs. This indicates the presence of significant fine-grained material possibly in the form of thin horizontal silt beds or lenses.

4. The boreholes logged were drilled using an air-rotary rig. This means that the geotechnical logs are unlikely to identify thin silt layers and that the exact depth between lithological boundaries may not be exact.

6.2 Monitoring Well X16B

The results for monitoring well X16B are shown on Figure 2. X16B is an older well having been installed in 1981 and is the furthest downstream below the Cross Valley Dam. It is within approximately 50 m of Rose Creek. Other than the top 3 m, the entire log shows native overburden material. The water table is approximately 3 m below the current ground surface, placing it immediately below the organic layer in the clean sands and gravel. The vertical displacement between the geophysical logs and the borehole log shown in Figure 2 is a result of the fact that the borehole log shows the Johnson screen being placed at the start of the bottom sandy gravel layer. As the Johnson screen is made of stainless steel it is accurately detected in the Conductivity and Inphase logs at a depth of 26.7 m below ground surface. When aligning the sandy gravel layer in the borehole log to this depth it appears that approximately 0.8 m of the excavation spoil has been removed over the years. It is unclear whether this is in fact the case or whether this is in fact a result of errors in the original borehole log.

The natural gamma logs shows several features of interest:

1. A fine-grained possible clayey layer exists immediately above the organic layer, possibly a result of construction activity or an accidental tailings release in 1976.

2. The most permeable layers exist between 3.5 to 5 m and below 27 m.

3. Between the most permeable layers the material gradually becomes less permeable reaching its least permeable layer where the borehole log shows a silt layer between 16 and 17 m.

4. The variability in the natural gamma logs within the natural overburden soils suggests thin horizontal silty beds or lens are common, far more so than the borehole logs suggest.

The apparent conductivity and inphase logs are relatively uninteresting to look at. Of note are:

1. An apparent conductivity spike in the order of approximately 100 mS/m is seen at a depth of 4.5 m.

2. The modeled layer associated with the apparent conductivity spike mentioned in point 1. is quite thin, at 0.25 m, shows a true conductivity of about 300 mS/m, and is close to the surface of the water table.

3. Conductivity readings throughout the rest of the log are between 10 and 25 mS/m.

4. Conductivity and Inphase reading spikes are seen at 4.2, 8.6, 19.6 and 23.5 m. It is thought that these spikes may be caused by spacing collars installed on the outside of the PVC pipe to center it during installation, metal strapping on the outside of PVC pipe and metal debris left in the hole by the drill bit.

5. At 26.1 m a strong metallic response is seen on both the conductivity and the inphase logs, marking the top of the Johnson screen at 26.7 m (the influence of steel casings are seen from 0.6 m away as the conductivity probe is lowered down the hole).

To summarize the results for X16B, two facts are apparent. Firstly, the majority of the well shows little evidence of any electrolytes in the pore fluids with apparent and modeled conductivity values that are typical for slightly silty sands and gravels of glacial or fluvial origin. Secondly, only one potentially contaminated zone is present at 4.5 m. Interpretation of this location is somewhat problematic and the modeling results are not entirely satisfactory, due to the fact that the apparent conductivity response seen is thought to be a summation of both a metal spacing collar and a thin contaminated zone. What is apparent from the modeling is that the true conductivity level of this thin zone is modeled to be about 300 mS/m and is likely quite thin, probably around 0.25 m in thickness. It would appear from the borehole log that this zone corresponds to the base of clean sand and gravel and correlates with the shallow permeable zone seen in the gamma log. It should be noted however, that there is considerable potential error in the modeled conductivity value. As can be seen from equation 1 in section 5.4, a small change in the modeled thickness will result in a significant change in the modeled conductivity, and at 0.25 m the layer thickness is at the limit of the resolution of the conductivity probe to detect.

6.3 Monitoring Well X17B

The results for monitoring well X17B are shown on Figure 3. X17B is also an older well having been installed in 1981 and is approximately halfway between X16B and the Cross Valley Dam. The entire log shows native overburden material. The water table is approximately 2 m below the current ground surface immediately placing it within a layer described as consisting of silty sands and gravels. The Johnson screen was placed at the start of the bottom sandy gravel layer at 18.5 m. The Johnson screen was detected in the Conductivity and Inphase logs at this depth.

The natural gamma logs shows a similar profile to X16B. Specifically:

1. The current water table exists immediately below the least permeable zone in the log.
2. A permeable zone 0.5 to 1 m thick is present below this zone at 2.0 m below grade, but it is not as well defined as with X16B.
3. The most permeable soils appear to be below 17 m from grade.
4. As with X16B, the variability in the natural gamma logs within the natural overburden soils suggests thin horizontal silty beds or lens are common, far more so than the borehole logs suggest.

The apparent conductivity and inphase logs are very similar to X16B. Of note are:

1. An apparent conductivity spike in the order of approximately 60 mS/m is seen at a depth of 2.2 m close to the surface of the water table.
2. The modeled layer associated with the apparent conductivity spike mentioned in the previous point, is also quite thin, at 0.25 m with the modeled true conductivity value being 100 mS/m.
3. Conductivity readings throughout the rest of the log are between 20 and 30 mS/m.
4. Conductivity and Inphase reading spikes are seen at 2.2, 4.6, 10.8 and 17 m. It is thought that these spikes are caused by spacing collars installed on the outside of the PVC pipe to center it during installation, metal strapping on the outside of PVC pipe or metal debris left in the hole by the drill bit.
5. At 17.9 m a strong metallic response is seen on both the conductivity and the inphase logs, marking the top of the Johnson screen at 18.5 m.

The discussion regarding the conductive zone in X16B holds for this zone in X17B. The location of the conductive zone (2.2 m) in X17B appears to correspond with the permeable zone at 3.5 m to 5 m in X16B.

6.4 Monitoring Well 96-03B

The geophysical logs for 96-03B (see Figure 4) are remarkable only in so far as they show little variation and no evidence of conductive contaminant zones.

The surface casing terminates at 0.4 m in depth below grade and the screening in this well is not made of stainless steel. The metal spacers and/or metal strapping on the outside of PVC pipe and metal debris left in the hole by the drill bit are also seen very clearly in the inphase log at 1.8, 9.0, 11.2, 12.0, and 18.0 m below grade. Typical conductivity values are around 10 mS/m.

Permeability in the Gravel Fill at surface is variable with the least permeable material being 1.5 m below grade. Natural overburden appears to start at a depth of 3 m below grade. There are two zones that appear more permeable, one 1 m thick at 8 m corresponding to a Gravel layer in the borehole log and one 1.5 m thick at 17.5 m corresponding to a well graded Sand layer. The natural gamma logs as a whole are consistent with the character of those seen in X16B and X17B and the same comments regarding thin silt layers are thought to apply.

6.5 Monitoring Well 96-04D

The geophysical logs for 96-04D (see Figure 5) are similar to 96-03B and no evidence of conductive contaminant zones are seen.

The surface casing terminates at 0.3 m in depth below grade and the screening in this well is not made of stainless steel. The metal spacers and/or metal strapping on the outside of PVC pipe or metal debris left in the hole by the drill bit are also seen very clearly in the inphase log every 6 m. Their regularity suggests that an explanation associated with the pipe installation is more likely. Typical conductivity values are between 10 and 20 mS/m.

Permeability in the Gravel Fill at surface is variable with the least permeable material being 2 m below grade. Natural overburden appears to start at a depth of 3 m below grade. There are three zones that appear more permeable, one between 5 and 7 m corresponding to a Sand layer in the borehole log and two more 1 m thick at 10 m and 22 m. The second two layers do not appear to correspond to specific layers in the borehole logs. The natural gamma logs as a whole are consistent with those seen in X16B and X17B and the same comments regarding thin silt layers are thought to apply.

6.6 Monitoring Well 96-05C

The geophysical logs collected at monitoring well 96-05C (see Figure 6) are the most interesting logs and clearly illustrate both the thickness and history of the tailings placed at this location.

The natural gamma logs show the following points of interest:

1. The tailings are quite clearly identified in the natural gamma log and appear to be 8.5 m thick.

2. The natural gamma readings for the tailings are significantly lower than for the natural overburden material. It is thought that this is not necessarily a reflection of more permeable soils but rather a result of higher concentrations of gamma ray particle absorbing materials in the tailings, such as lead.

3. On the basis of 2. (above), it would appear that there is a 1 m zone between 0.5 and 1.5 m below grade where this gamma ray absorbing material has lower concentrations, possibly because some of the gamma particle absorbing material has been leached out.

4. Below the tailings the natural gamma profile is similar to that seen in the native overburden in all of the other wells.

5. Permeability in the native overburden appears to gradually decrease until 26.0 m below grade where there is a noticeable increase in the permeability. This corresponds to a possible zone of cobbles in the borehole log.

The apparent conductivity log provides specific information regarding the history of the tailing placement. As can be seen, the calculated conductivity response using a multi-layered model exactly duplicates the measured apparent conductivity values. The modeled conductivity log shows that the tailings consist of at least seven significant layers with dramatically different conductivities. It is thought that these layers may reflect differences in the tailing treatment at the mill site over time as they were progressively deposited in the Intermediate impoundment area. An alternative explanation to the layering seen, is that it is the result of the downward migration of an acid / oxidation front.

Peak true conductivity levels are seen at 5.2 m below grade at 750 mS/m (7500 microS/cm). At 6 m below grade the true conductivity values are 525 mS/m (5250 microS/cm). Conductivity levels measured from ground water samples taken from this location are in the range of 150 to 700 mS/m (1.5 to 7.0 mS/cm) and therefore, correlate with the range of true conductivity values calculated in the layered model based on the apparent conductivities logged.

Two moderately thin zones of elevated conductivity values 1 m thick are present immediately below the tailings in the sand gravel fill layer. Modeled values for the true conductivity levels in these zones are approximately 350 mS/m (3500 microS/cm) and 40 mS/m (400 microS/cm). Although the true conductivity readings immediately below the tailings are elevated above background levels, the magnitudes are lower than those seen from within the tailings material. It is not felt that the tailings have masked a thin (< 0.25 m thick) high conductive zone at this depth.

There is little evidence of elevated conductivity values below 9.5 m below grade with measured conductivity values in the same range as the other wells in native overburden material (10 to 15 mS/m).

The surface casing terminates 0.3 m below grade and evidence of metal pipe spacers, steel banding or drill bit debris are seen at 8.5, 11.0 and 27.0 m below grade.

It should be noted that due to the close match between the measured apparent conductivity log and the modeled conductivity log as well as the general agreement with the conductivities measured from the water samples it is felt that the interpreted true conductivity values shown in Figure 6 accurately represent the in situ conditions. The modeled layer thickness by their nature may not exactly reflect reality, but it is felt that they do provide a good overview of actual conditions.

7.0 CONCLUSIONS

The geophysical logs successfully characterized the 5 monitoring wells profiled. Main conclusions are as follows:

1. Two 1.0 m zones with elevated conductivity levels were identified immediately below the tailings in well 96-05C.

2. A shallow, thin (0.25 m) conductive zone was identified within 5.0 m of the surface in wells X16B and X17B.
3. No noticeably elevated conductivity zones were identified anywhere in 96-03B and 96-04D and at depth in 96-05C, X16B or X17B.
4. The natural gamma logs corroborate and provide further insight into the overburden profile described in the borehole logs.

8.0 RECOMMENDATIONS

Although the geophysical logs successfully characterized the conductivity profiles in the existing monitoring wells, 4 of the 5 monitoring wells terminate in overburden. It is therefore not possible to determine if other conductive zones exist below these wells. In addition it is not felt that sufficient wells are present to meaningfully relate the results between the three groups of wells. In order to better characterize the tailings it will be necessary to place new monitoring wells at strategic locations dictated by an understanding of the groundwater hydrology of the site. In order to optimize the placement of screening intervals the wells should be installed in a fashion that would allow conductivity logging of the well prior to final placement of the screens.

9.0 CLOSURE

EBA Engineering Consultants Ltd. has appreciated the opportunity to work with Environment Canada on this project. Should any questions arise concerning the contents of this report please contact the undersigned.

Respectfully Submitted,
EBA Engineering Consultants Ltd.

Neil S. Parry
Senior Geophysicist
(Direct Line: 780-451-2130, Ext. 274)

J. Richard Trimble, P.Eng.
Project Director, Yukon Region
(Direct Line 867-668-2071. Ext. 22)

NSP'ta

X:\0201\Projects\2000\00-14352\14352-R03.doc

FIGURES

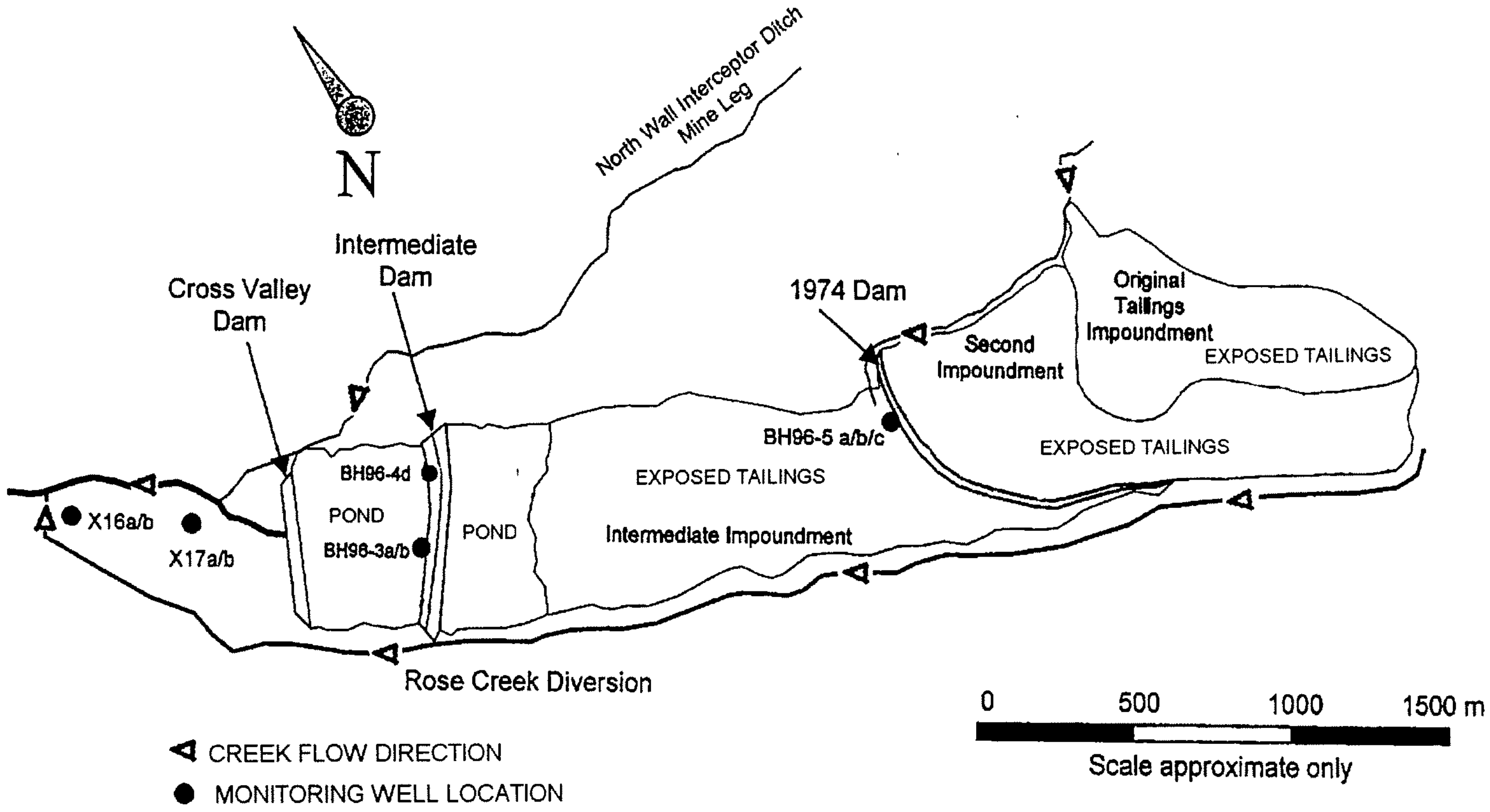
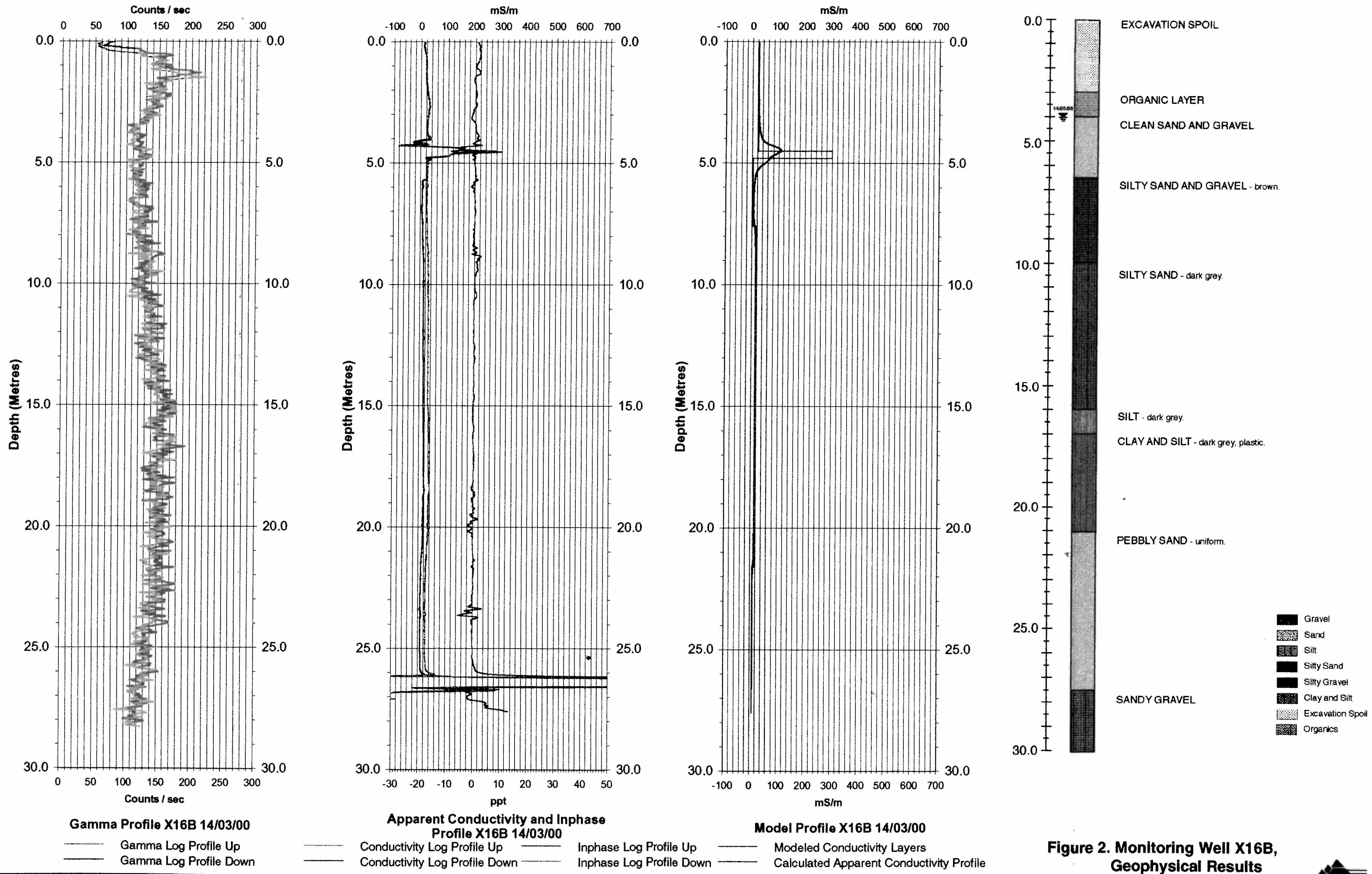


Figure 1. Faro Down Valley Tailings Area, Well Sites for Geophysical Program

14352NSP07 freehand



Gamma Profile X16B 14/03/00

Gamma Log Profile Up
Gamma Log Profile Down

Apparent Conductivity and Inphase Profile X16B 14/03/00

Conductivity Log Profile Up
Conductivity Log Profile Down
Inphase Log Profile Up
Inphase Log Profile Down

Model Profile X16B 14/03/00

Modeled Conductivity Layers
Calculated Apparent Conductivity Profile

Figure 2. Monitoring Well X16B, Geophysical Results

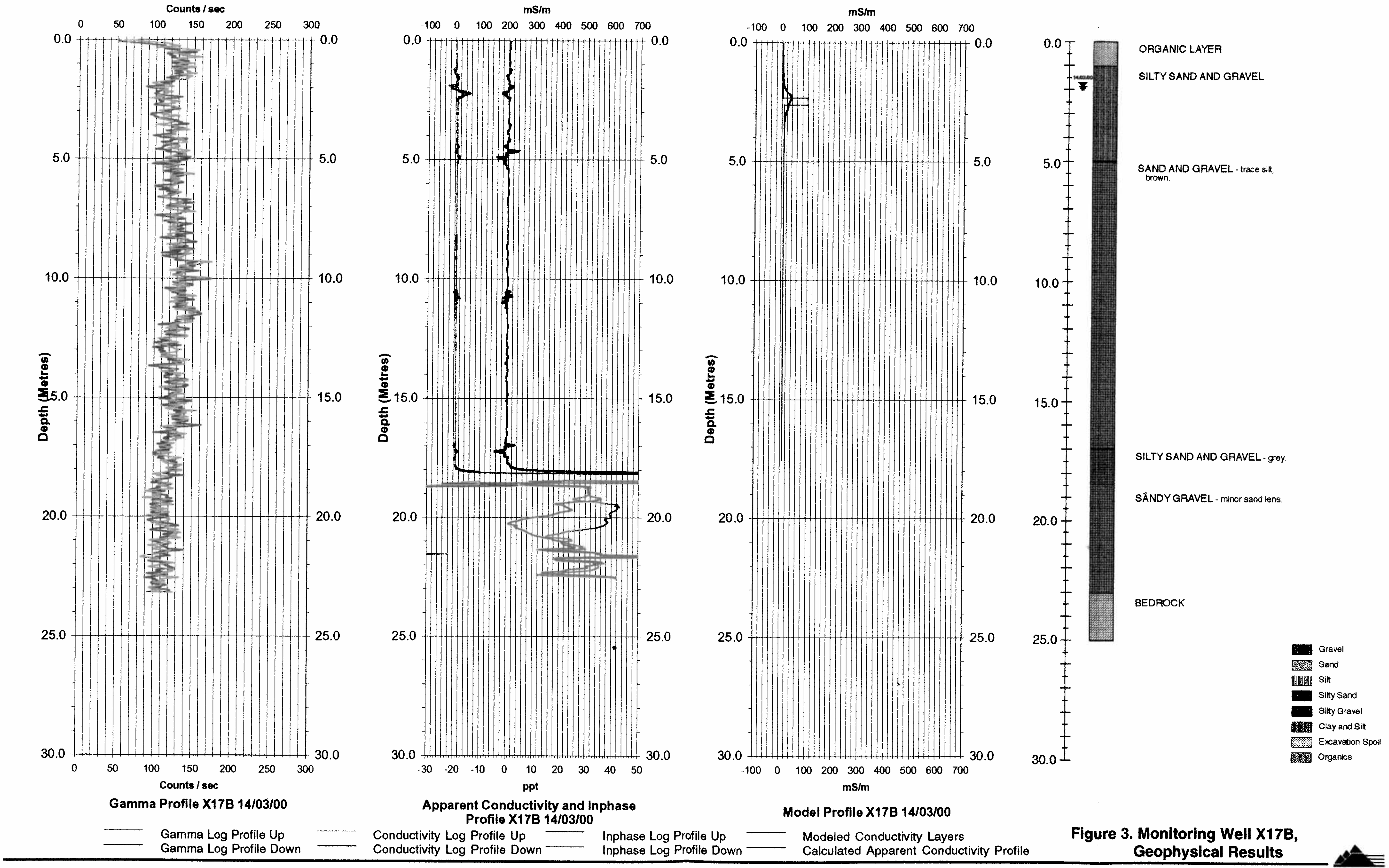
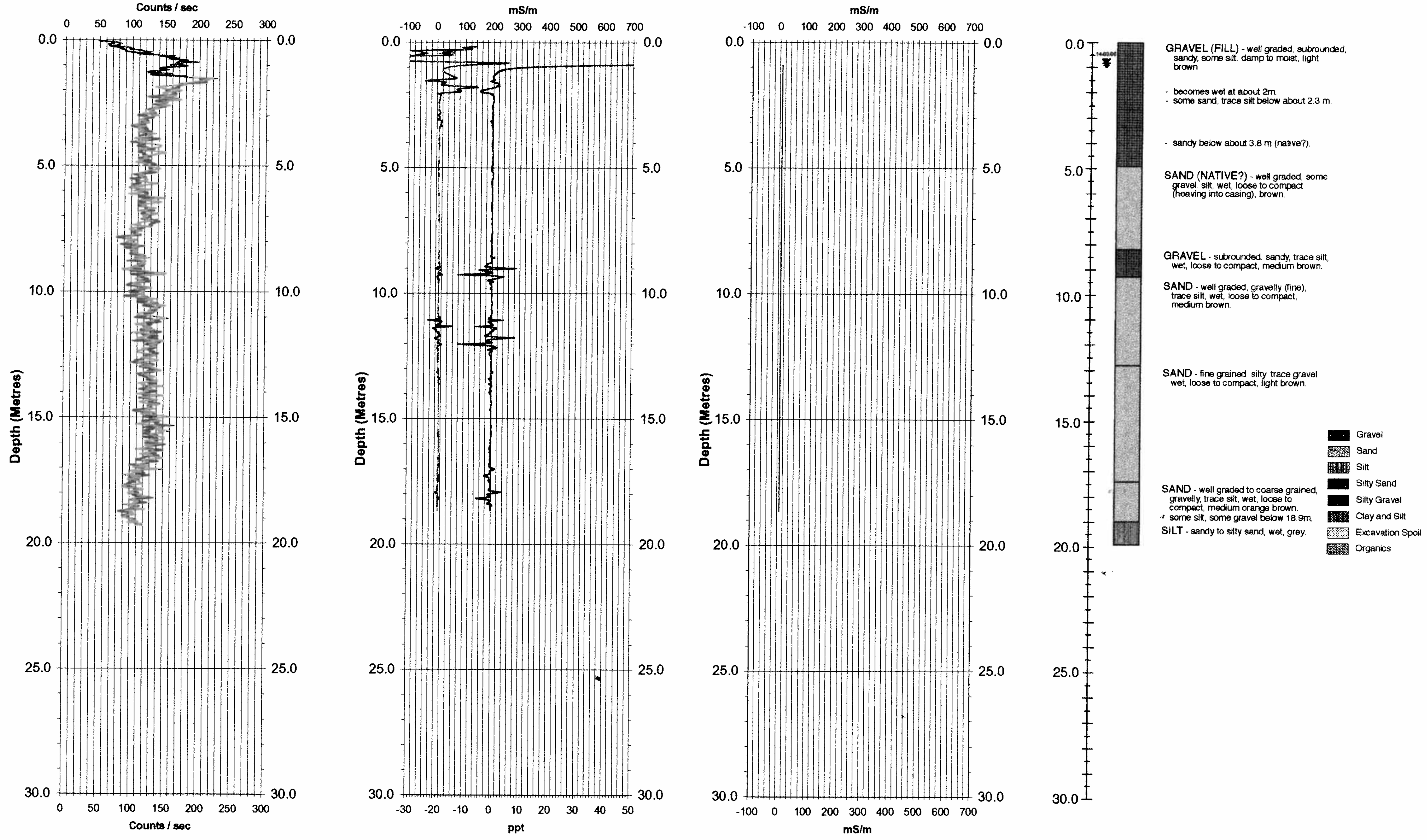


Figure 3. Monitoring Well X17B, Geophysical Results



GRAVEL (FILL) - well graded, subrounded, sandy, some silt. damp to moist, light brown

- becomes wet at about 2m.
- some sand, trace silt below about 2.3 m.

- sandy below about 3.8 m (native?).

SAND (NATIVE?) - well graded, some gravel. silt, wet, loose to compact (heaving into casing), brown.

GRAVEL - subrounded. sandy, trace silt, wet, loose to compact, medium brown.

SAND - well graded, gravelly (fine), trace silt, wet, loose to compact, medium brown.

SAND - fine grained silty trace gravel wet, loose to compact, light brown.

SAND - well graded to coarse grained, gravelly, trace silt, wet, loose to compact, medium orange brown.
* some silt, some gravel below 18.9m.

SILT - sandy to silty sand, wet, grey.

Gamma Profile 03B 14/03/00

Apparent Conductivity and Inphase Profile 03B 14/03/00

Model Profile 03B 14/03/00

Gamma Log Profile Up
Gamma Log Profile Down

Conductivity Log Profile Up
Conductivity Log Profile Down

Inphase Log Profile Up
Inphase Log Profile Down

Modeled Conductivity Layers
Calculated Apparent Conductivity Profile

Figure 4. Monitoring Well 03B, Geophysical Results

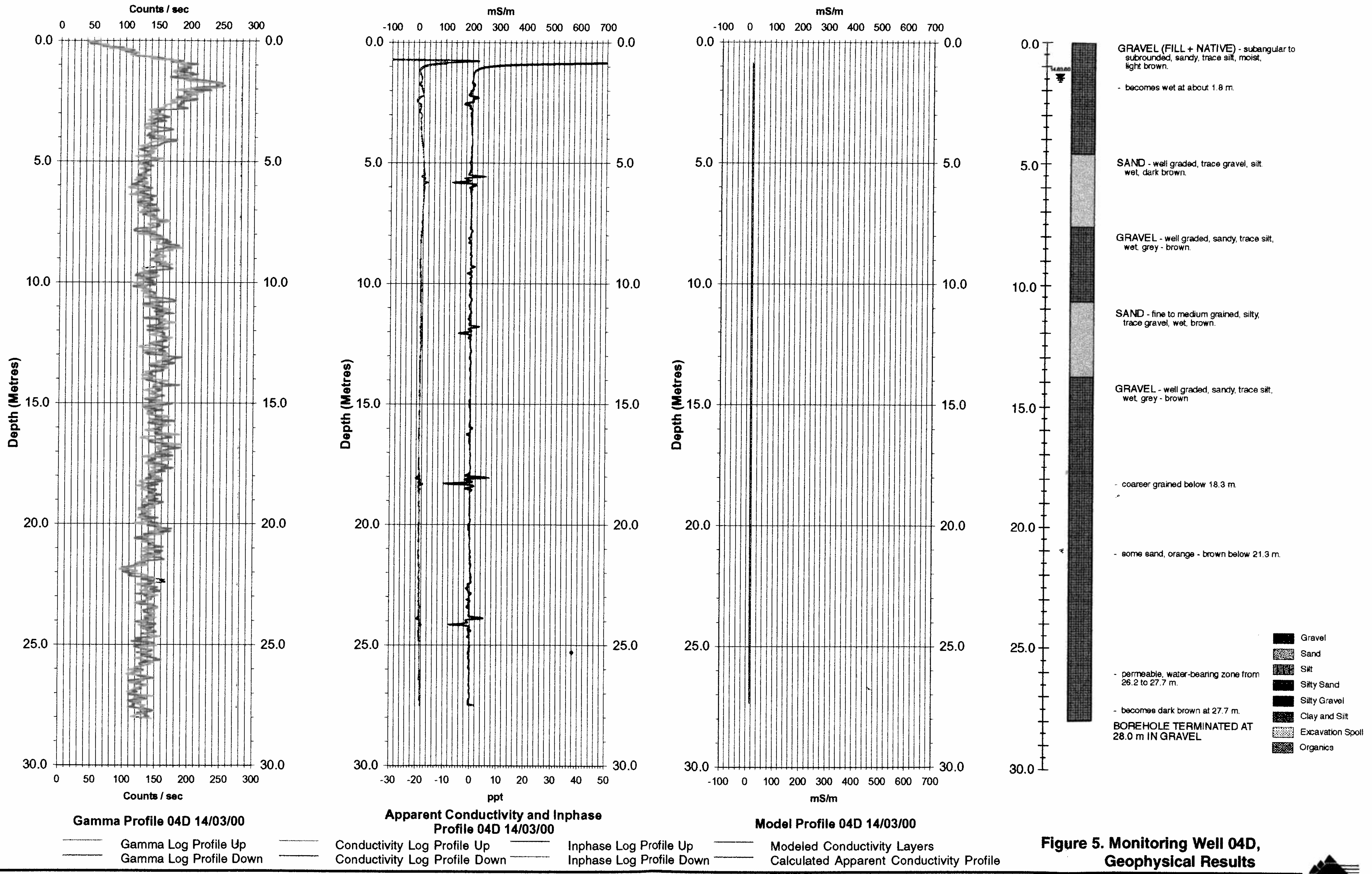
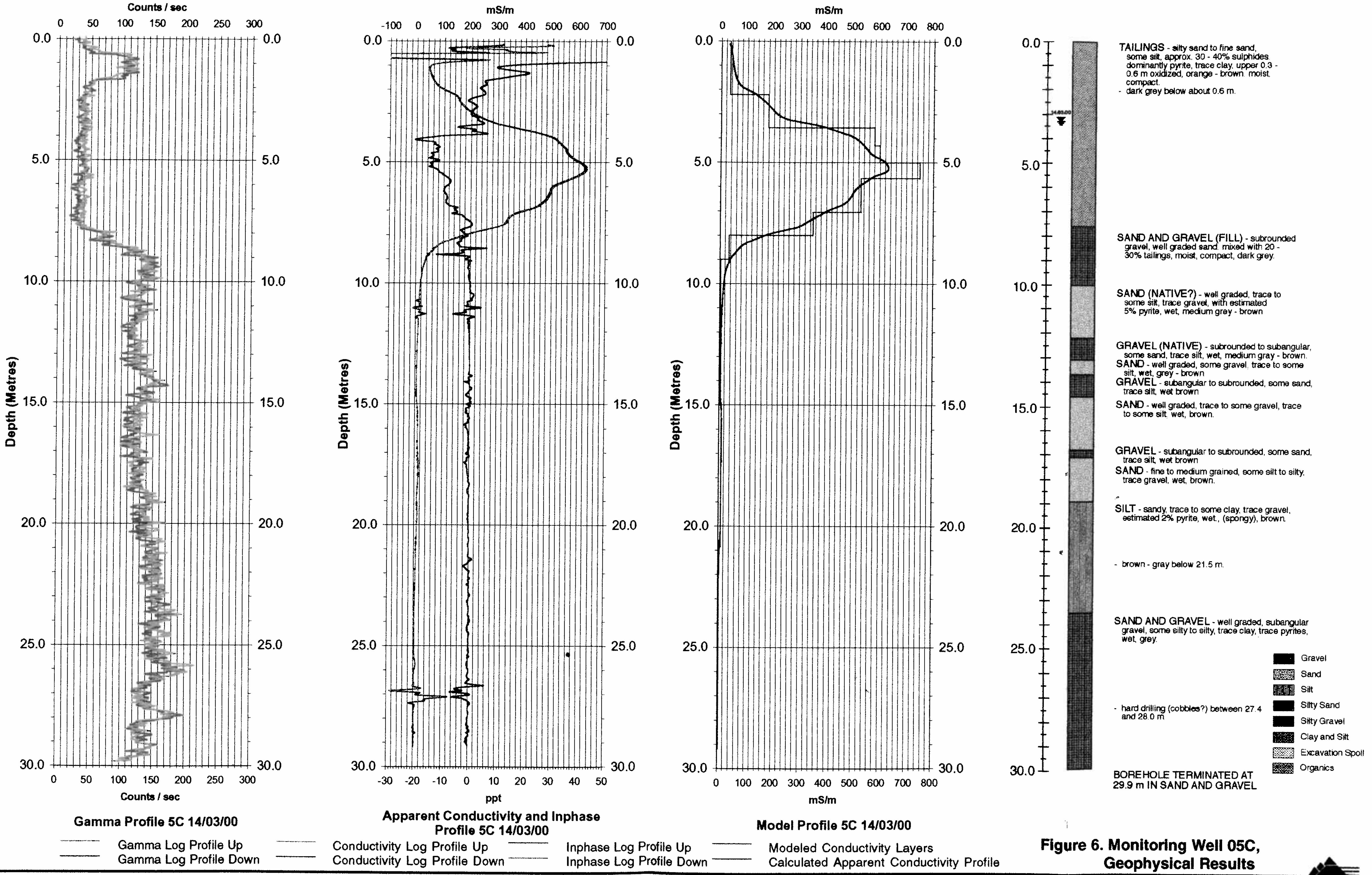


Figure 5. Monitoring Well 04D, Geophysical Results



TAILINGS - silty sand to fine sand, some silt, approx. 30 - 40% sulphides dominantly pyrite, trace clay, upper 0.3 - 0.6 m oxidized, orange - brown. moist, compact.
- dark grey below about 0.6 m.

SAND AND GRAVEL (FILL) - subrounded gravel, well graded sand. mixed with 20 - 30% tailings, moist, compact, dark grey.

SAND (NATIVE?) - well graded, trace to some silt, trace gravel, with estimated 5% pyrite, wet, medium grey - brown

GRAVEL (NATIVE) - subrounded to subangular, some sand, trace silt, wet, medium gray - brown.

SAND - well graded, some gravel. trace to some silt, wet, grey - brown

GRAVEL - subangular to subrounded, some sand, trace silt, wet brown

SAND - well graded, trace to some gravel, trace to some silt. wet, brown.

GRAVEL - subangular to subrounded, some sand, trace silt, wet brown

SAND - fine to medium grained, some silt to silty, trace gravel, wet, brown.

SILT - sandy, trace to some clay, trace gravel, estimated 2% pyrite, wet., (spongy), brown.
- brown - gray below 21.5 m.

SAND AND GRAVEL - well graded, subangular gravel, some silty to silty, trace clay, trace pyrites, wet, grey.
- hard drilling (cobbles?) between 27.4 and 28.0 m

BOREHOLE TERMINATED AT 29.9 m IN SAND AND GRAVEL

Figure 6. Monitoring Well 05C, Geophysical Results

APPENDIX A

APPENDIX A

A.1 EM39 Conductivity Probe Theory of Operation

The Geonics EM39 Conductivity Probe is a geophysical tool that measures the ground's electrical conductivity or resistivity using electrical induction techniques. Specifically it achieves this by inducing a constant amplitude, alternating electric current loop in the material surrounding the probe by generating a strong alternating magnetic field using a transmitting coil in a dipole configuration. The dipole configuration ensures that the electric currents generated (also called ground loops) are coaxial to the probe's axis, and focussed around the center of the probe. These current loops once they are established, in turn generate their own secondary magnetic fields, which are detected by a dipole receiver, a fixed separation from the transmitter. In the case of the EM39 this separation is 0.5 m. The strength of the secondary magnetic field and the magnitude of the electric current it induces in the receiving coil is proportional to the conductivity of the material surrounding the borehole and therefore can be calibrated to provide a measure of the surrounding materials conductivity.

The advantage of this design is that the induction probe can be designed to minimize the influence of the borehole fluids. In the case of the EM39 it is designed to be sensitive to electrical properties up to 1.0 m away from the borehole. This means that the conductivity of the borehole fluid will not influence the results. A disadvantage however is that the borehole casing has to be nonconductive otherwise it will electrically screen the probe and prevent it from inducing a ground loop in the surrounding material. This means that the probe is ineffective in steel cased holes, but works well in PVC, ABS or fiberglass cased holes.

A second consideration is that the conductivities measured are an apparent conductivity response and to determine the true response one must integrate the results. In practical terms this means that as one approaches an abrupt change in conductivity, what the probe detects is a gradual rise in conductivity values over a 0.5 m distance until the conductivity measured, peaks at the apparent conductivity value. Therefore for layers thicker than 0.5 m the conductivity measured is reflective of the materials' true conductivity and the relationship is quantifiable. For layers between 1.5 and 5 m the measured conductivity is within 20% of the true conductivity. For layers greater than 5 m thick the measured conductivity approximately equals the true conductivity. By modeling the response and matching the modeled conductivity curve with that measured, one can determine what the true resistivity profile is. It should be remembered however that the modeling solution is non-unique for layers thinner than 0.25 m. One may vary both the conductivity amplitude and the layer thickness to obtain the same curve response therefore the solutions are not unique. It should also be noted that the conductivities measured are measured at a frequency of 39.3 kHz. The electrical properties of soils do vary with frequency due to attenuation effects, therefore there is not necessarily a direct correlation to values measured using handheld probes or soil boxes, as these readings are quite frequently taken at much lower frequencies, or even DC levels.

A.2 Natural Gamma Probe Theory of Operation

The natural gamma probe can be thought of as an electronic counter that is sensitive to gamma ray particles. Each time a gamma ray particle passes through the scintillation chamber detector the electronic counter is incremented by one. Therefore the higher the counts/second the more gamma ray particles have been detected. In natural soils the source of this gamma radiation are three naturally occurring radioactive decay sequences. They are:

1. Potassium40
2. Thorium
3. Uranium-Radium

In most soils the radioactive Potassium40 sequence is by far the most common. Radioactive Potassium comprises 0.01% of all Potassium, but where Potassium is present, that percentage holds. The Uranium and Thorium sequences occur in sedimentary materials or may be present when specific radioactive minerals such as Monazite are present. In addition, because of their absorption and ion exchange capacity, clay minerals have the ability to absorb the heavy radioactive isotopes released by these two sequences as well as retaining their own intrinsic radioactive sources. As a result clay minerals have much higher natural gamma levels than other soils. Therefore typically speaking, when one is dealing with overburden material, higher gamma readings indicate a higher proportion of fine-grained clayey particles, while lower readings are more indicative of sands and gravels. One should note however that if concentrations of particular elements are present gamma particles may be preferentially absorbed yielding lower than usual readings. Lead would one such material.

There is always a degree of scatter in the gamma counts measured due to the statistical nature of the measurement. Having said that, the vertical discrimination of the gamma probe is quite good due to the physically small size of the sensor, therefore it is quite capable of detecting small beds in the order of several centimetres in size.

Yukon
Economic Development

Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

ISBN 1-55018-984-0